# SUGGESTED METHOD FOR IN SITU DETERMINATION OF DIRECT SHEAR STRENGTH

(International Society for Rock Mechanics)

## 1. Scope

1.1 This test measures peak and residual direct shear strengths as a function of stress normal to the sheared plane. Results are usually employed in limiting equilibrium analysis of slope stability problems or for the stability analysis of dam foundations (Notes 1-3).

NOTE 1—Direct shear strength can be determined in the laboratory (using the method described in RTH 203) if the plane to be tested is smooth and flat in comparison with the size of specimen, and if the specimen can be cut and transported without disturbance.

NOTE 2—Definitions (clarified in Figs. 5 and 6):

Peak shear strength - the maximum shear stress in the complete shear stress displacement curve.

Residual shear strength - the shear stress at which no further rise or fall in shear strength is observed with increasing shear displacement. A true residual strength may only be reached after considerably greater shear displacement than can be achieved in testing. The test value should be regarded as approximate and should be assessed in relation to the complete shear stress-displacement curve.

Shear strength parameters c and $\phi$ - respectively, the intercept and angle to the normal stress axis of a tangent to the shear strength-normal stress curve at a normal stress that is relevant to design (see Fig. 6).

NOTE 3—The measured peak strength can be applied directly to full-scale stability calculations only if the same type and size of roughness irregularities are present on the tested plane as on a larger scale. If this is not the case, the true peak strength should be obtained from the test data using appropriate calculations (for example, Patton, F. D., 1966, Proc. 1st Int. Cong. Rock Mech. ISRM, Lisbon, Vol 1, pp. 509-512;

Ladanyi, B. and Archambault, G., 1970. In "Rock Mechanics - Theory and Practice," (W.II. Somerton, ed.), AIME, New York, pp. 105-125; Barton, N. R., 1971, Proc. Symp. ISRM, Nancy, Paper 1-8).

1.2 The inclination of the test block and system of applied loads are usually selected so that the sheared plane coincides with a plane of weakness in the rock (e.g., a joint, plane of bedding, schistosity, or cleavage), or with the interface between soil and rock or concrete and rock (Note 4).

NOTE 4—Tests on intact rock (free from planes of weakness) are usually accomplished using laboratory triaxial testing. Intact rock can, however, be tested in direct shear if the rock is weak and if the specimen block encapsulation is sufficiently strong.

1.3 A shear strength determination should preferably comprise at least five tests on the same test horizon with each specimen tested at a different but constant normal stress.

1.4 In applying the results of the test, the pore water pressure conditions and the possibility of progressive failure must be assessed for the design case as they may differ from the test conditions.

2. Apparatus

2.1 Equipment for cutting and encapsulating the test block, rock saws, drills, hammer and chisels, formwork of appropriate dimensions and rigidity, expanded polystyrene sheeting or weak filler, and materials for reinforced concrete encapsulation.

2.2 Equipment for applying the normal load (e.g., Fig. 1) including:

(a) Flat jacks, hydraulic rams, or dead load of sufficient capacity to apply the required normal loads (Note 5).

NOTE 5—If a dead load is used for normal loading, precautions are required to ensure accurate centering and stability. If two or more hydraulic rams are used for either normal or shear loading, care is needed to ensure that they are identically matched and are in exact parallel alignment. Each ram should be provided with a spherical seat. The travel of rams and particularly of flat jacks should be sufficient to accommodate the full anticipated specimen displacement. A normal displacement of ±5-10 mm may be expected, depending on the clay content and roughness of the shear surface.

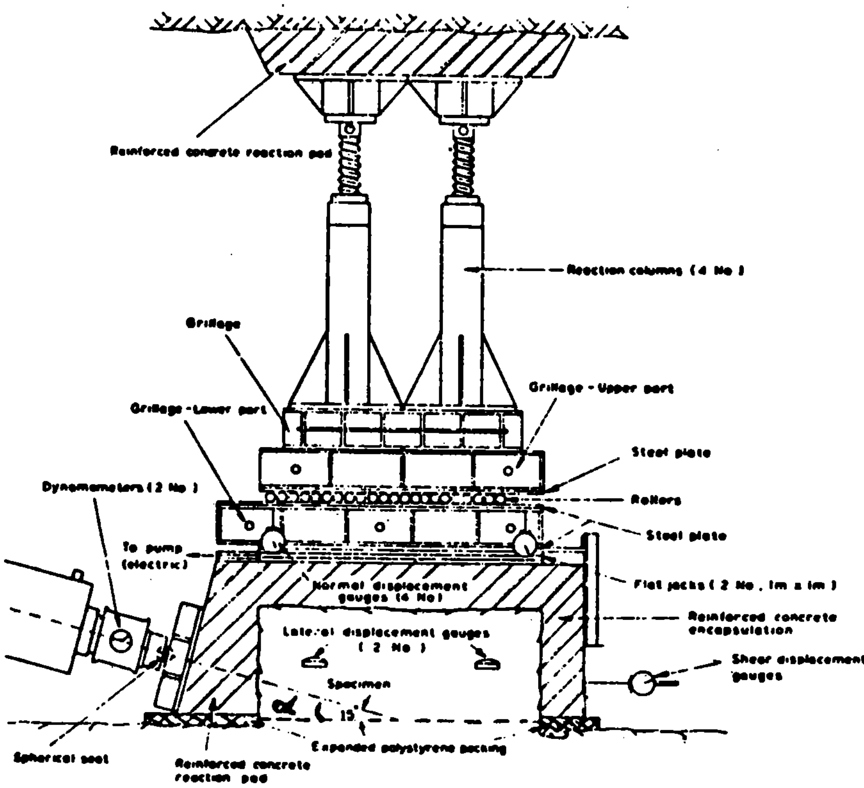



Fig. 1. Typical arrangement of equipment for in situ direct shear test.

(b) A hydraulic pump if used should be capable of maintaining normal load to within 2 percent of a selected value throughout the test.

(c) A reaction system to transfer normal loads uniformly to the test block, including rollers or a similar low friction device to ensure that at any given normal load, the resistance to shear displacement is less than 1 percent of the maximum shear force applied in the test. Rock anchors, wire ties, and turnbuckles are usually required to install and secure the equipment.

2.3 Equipment for applying the shear force (e.g. Fig. 1) including:

(a) One or more hydraulic rams (see Note 5) jacks of adequate total capacity with at least 70-mm travel.

(b) A hydraulic pump to pressurize the shear force system.

(c) A reaction system to transmit the shear force to the test block. The shear force should be distributed uniformly along one face of the specimen. The resultant line of applied shear forces should pass through the center of the base of the shear plane (Note 6) with an angular tolerance of ±5 deg.

NOTE 6--The applied shear force may act in the plane of shearing so that the angle $\alpha$ is 0 (Fig. 1). This requires a cantilever bearing member to carry the thrust from the shear jacks to the specimen. If a method is used where the shear force acts at some distance above the shear plane, the line of action of the shear jacks should be inclined to pass through the center of area of the shear plane. The angle for a specimen 700 by 700 by 350 mm approximates to 15 deg depending on the thickness of encapsulation. Tests where both shear and normal forces are provided by a single set of jacks inclined at greater angles to the shear plane are not recommended, as it is then impossible to control shear and normal stresses independently.

2.4 Equipment for measuring the applied forces including one system for measuring normal force and another for measuring applied shearing force with an accuracy better than ±2 percent of the maximum forces reached in the test. Load cells (dynamometers) or flat jack pressure measurements may be used. Recent calibration data applicable to the range of testing should be appended to the test report. If possible, the gages should be calibrated both before and after testing.

2.5 Equipment for measuring shear normal, and lateral displacements:

(a) Displacements should be measured (e.g., using micrometer dial gages (Note 7)) at eight locations on the specimen block or encapsulating material, as shown in Fig. 2.

NOTE 7—The surface of encapsulating material is usually insufficiently smooth and flat to provide adequate reference for displacement gages, and glass plates may be cemented to the specimen block for this purpose. These plates should be of adequate size to accommodate movement of the specimen. Alternatively, a tensioned wire and pulley system with gages remote from the specimen can be used. The system as a whole must be reliable and conform with specified accuracy requirements. Particular care is needed in this respect when employing electric transducers or automatic recording equipment.

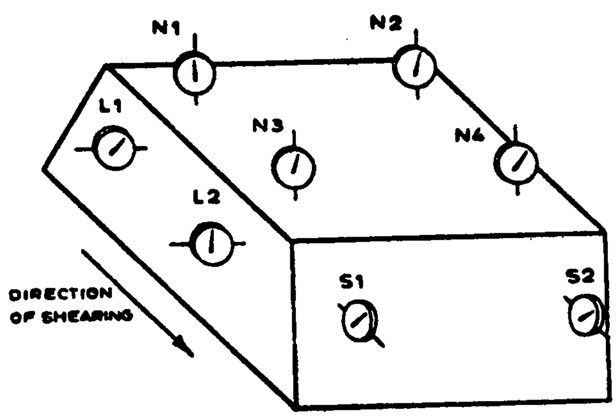



Fig. 2. Arrangement of displacement gages (S1 and S2 for shear displacement L1 and L2 for lateral displacement, N1-N4 for normal displacement.

(b) The shear displacement measuring system should have a travel of at least 70 mm and an accuracy better than 0.1 mm. The normal and lateral displacement measuring systems should have a travel of at least 20 mm and an accuracy better than 0.05 mm. The measuring reference system (beams, anchors, and clamps) should, when assembled, be sufficiently rigid to meet these requirements. Resetting of gages during the test should be avoided if possible.

3. Procedure

3.1 Preparation:

(a) The test block is cut to the required dimensions (usually 700 x 700 x 350 mm) using methods that avoid disturbance or loosening of the block (Notes 8 and 9). The base of the test block should coincide with the plane to be sheared and the direction of shearing should correspond if possible to the direction of anticipated shearing in the full-scale structure to be analyzed using the test results. The block and particularly the shear plane should, unless otherwise specified, be retained as close as possible to its natural in situ water content during preparation and testing, e.g., by covering with saturated cloth. A channel approximately 20 mm deep by 80 mm wide should be cut around the base of the block to allow freedom of shear and lateral displacements.

NOTE 8--A test block size of 700 x 700 x 350 mm is suggested as standard for in situ testing. Smaller blocks may be permissible, for example if the surface to be tested is relatively smooth; larger blocks may be needed when testing very irregular surfaces. The size and shape of test block may for convenience be adjusted so that faces of the block coincide with natural joints or fissures; this minimizes block disturbance during preparation. Irregularities that would limit the thickness or emplacement of encapsulation material or reinforcement should be removed.

NOTE 9--It is advisable, particularly if the test horizon is inclined at more than 10-20 deg to the horizontal, to apply a small normal load to the upper face of the test specimen while the sides are cut, to prevent premature sliding and also to inhibit relaxation and swelling. The load, approximately 5-10 percent of that to be applied in the test, may for example be provided by screw props or a system of rock bolts and crossbeams and should be maintained until the test equipment is in position.

(b) A layer at least 20 mm thick of weak material (e.g. foamed polystyrene) is applied around the base of the test block, and the remainder of the block is then encapsulated in reinforced concrete or similar material of sufficient strength and rigidity to prevent collapse or significant distortion of the block during testing. The encapsulation formwork should be designed to ensure that the load bearing faces of the encapsulated block are flat (tolerance ±1 mm) and at the correct inclination to the shear plane (tolerance ±2 deg).

(c) Reaction pads, anchors, etc., if required to carry the thrust from normal and shear load systems to adjacent sound rock, must be carefully positioned and aligned. All concrete must be allowed time to gain adequate strength prior to testing.

3.2 Consolidation:

(a) The consolidation stage of testing is to allow pore water pressures in the rock and filling material adjacent to the shear plane to dissipate under full normal stress before shearing. Behavior of the specimen during consolidation may also impose a limit on permissible rate of shearing (see paragraph 3.3(c)).

(b) All displacement gages are checked for rigidity, adequate travel, and freedom of movement, and a preliminary set of load and displacement readings is recorded.

(c) Normal load is then raised to the full value specified for the test, recording the consequent normal displacements (consolidation) of the test block as a function of time and applied loads (Figs. 3 and 4).

DIRECT SHEAR TEST DATA SHEET

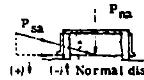
Client: Project: Concrete Dam Location: Alcântara Loc. No.: Block No.:

TEST BLOCK SPECIFICATION See drawings & photographs Nos.:

General rock description, index properties and water conditions
Phyllite, sound to moderately weathered Normal conditions

Description and index properties of surface to be sheared Type;
Dip; Dip direction; Roughness; Filling & alteration;
Persistance; Spacing of set; Surface dimensions; 0.70 x 0.70 Initial area A; 0.490 $m^2$

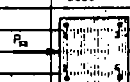
FORCES




$P_n = P_{na} + P_{sa} \sin \alpha$
$P_s = P_{sa} \cos \alpha$
$\sigma_n = P_n / A$
$\tau = P_s / A$

$\alpha$ = 15° $\sigma_n$ (nominal)

| 1 Time elapsed (min) | 2 Applied normal force $P_n$ Reading | Force (kN) | 3 Normal displacement $\Delta_n$ Reading 1 | 2 | 3 | 4 | Average (mm) | 4 Applied shear force $P_s$ Reading | Force (kN) | 5 Shear displacement $\Delta_s$ Reading 1 | 2 | Average (mm) | 6 Contact area A (corrected) $m^2$ | 7 $P_{na}$ (kN) | 8 $\sigma_n$ ($MP_a$) | 9 $P_{sa}$ (kN) | 10 $\tau$ ($MP_a$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | | 196 | 0.100 | 0.070 | 0.130 | 0.070 | | | 0 | 0 | 0 | - | 0.490 | 196 | | 0 | |
| 35 | | 233 | 0.130 | 0.065 | 0.140 | 0.090 | | | 137 | 0.05 | 0.05 | 0.05 | | • | | 142 | |
| 48 | | 270 | 0.050 | 0.065 | 0.285 | 0.290 | | | 275 | 0.55 | 0.35 | 0.45 | | • | | 284 | |
| 64 | | 306 | -0.200 | 0.010 | 0.435 | 0.495 | | | 412 | 1.35 | 1.10 | 1.22 | | • | | 426 | |
| 87 | | 343 | -0.710 | -0.205 | 0.600 | 0.720 | | | 549 | 2.55 | 2.30 | 2.42 | | • | | 568 | |
| 109 | | 380 | -1.165 | -0.445 | 0.680 | 0.850 | | | 686 | 3.90 | 3.50 | 3.70 | | • | | 710 | |
| 131 | | 417 | -1.675 | -0.615 | 0.710 | 0.970 | | | 824 | 5.15 | 4.60 | 4.88 | | • | | 853 | |
| 154 | | 453 | -1.965 | -0.745 | 0.720 | 1.050 | | | 961 | 6.10 | 5.50 | 5.80 | | • | | 995 | |
| 172 | | 490 | -2.245 | -0.880 | 0.720 | 1.105 | | | 1098 | 7.20 | 6.50 | 6.85 | | • | | 1137 | |
| 189 | | 527 | -2.480 | -1.055 | 0.695 | 1.165 | | | 1235 | 8.20 | 7.40 | 7.80 | | • | | 1279 | |
| 206 | | 504 | -2.750 | -1.205 | 0.640 | 1.165 | | | 1373 | 9.45 | 8.45 | 8.95 | | • | | 1421 | |
| 234 | | 601 | -3.075 | -1.505 | 0.465 | 1.100 | | | 1510 | 11.00 | 10.00 | 10.50 | | • | | 1563 | |
| 252 | | 637 | -3.350 | -1.830 | 0.280 | 0.910 | | | 1647 | 12.45 | 11.40 | 11.92 | | • | | 1705 | |
| 264 | | 674 | -3.675 | -2.185 | 0.050 | 0.720 | | | 1764 | 14.00 | 12.80 | 13.40 | | • | | 1847 | |
| 276 | | 711 | -4.005 | -2.665 | -0.290 | 0.360 | | | 1922 | 15.55 | 14.40 | 14.98 | | • | | 1989 | |
| 289 | | 748 | -4.585 | -3.125 | -0.890 | -0.020 | | | 2059 | 17.60 | 16.45 | 17.02 | | • | | 2132 | |
| 293 | Rupture | 784 | -4.975 | -3.375 | -1.250 | -0.290 | | | 2196 | 20.00 | 19.55 | 19.78 | | • | | 2274 | |




Calibration data

Remarks

Tested by; Dates;
Checked by; Date;

Fig. 3. Example layout of direct shear test data sheet.

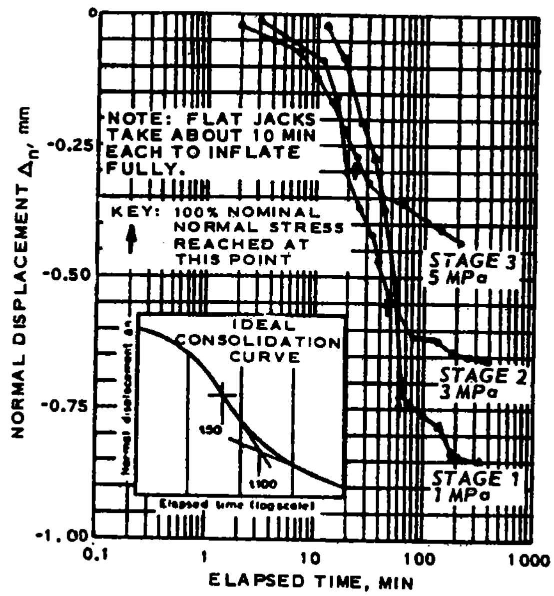



Fig. 4. Consolidation curves for a three-stage direct shear test, showing the construction used to estimate $t_{100}$.

(d) The consolidation stage may be considered complete when the rate of change of normal displacement recorded at each of the four gages is less than 0.05 mm in 10 minutes. Shear loading may then be applied.

3.3 Shearing:

(a) The purpose of shearing is to establish values for the peak and residual direct shear strengths of the test horizon. Corrections to the applied normal load may be required to hold the normal stress constant; these are defined in paragraph 4.5.

(b) The shear force is applied either in increments or continuously in such a way as to control the rate of shear displacement.

(c) Approximately 10 sets of readings should be taken before reaching peak strength (Figs. 3 and 5). The rate of shear displacement should be less than 0.1 mm/min in the 10-minute period before taking a set of readings. This rate may be increased to not more than 0.5 mm/min between sets of readings provided that the peak strength itself is adequately recorded. For a 'drained' test, particularly when testing clay-filled discontinuities, the total time to reach peak strength should exceed 6 $t_{100}$ as determined from the consolidation curve (see paragraph 4.1 and Fig. 4) (Note 10). If necessary, the rate of shear should be reduced on the application of later shear force increments delayed to meet this requirement.

NOTE 10—The requirement that total time to reach peak strength should exceed 6 $t_{100}$ is derived from conventional soil mechanics consolidation theory (for example Gibson and Henkel, Geotechnique 4, p 10-11, 1954) assuming a requirement of 90 percent pore water pressure dissipation. This requirement is most important when testing a clay-filled discontinuity. In other cases it may be difficult to define $t_{100}$ with any precision because a significant proportion of the observed "consolidation" may be due to rock creep and other mechanisms unrelated to pore pressure dissipation. Provided the rates of shear specified in the text are followed, the shear strength parameters may be regarded as having been measured under conditions of effective stress ("drained conditions").

(d) After reaching peak strength, readings should be taken at increments of from 0.5-5 mm shear displacement as required to adequately define the force-displacement curves (Fig. 5). The rate of shear displacement should be 0.02-0.2 mm/min in the 10-minute period before a set of readings is taken and may be increased to not more than 1 mm/min between sets of readings.

(e) It may be possible to establish a residual strength value when the specimen is sheared at constant normal stress and at least four consecutive sets of readings are obtained which show not more than 5 percent variation in shear stress over a shear displacement of 1 cm (Note 11).

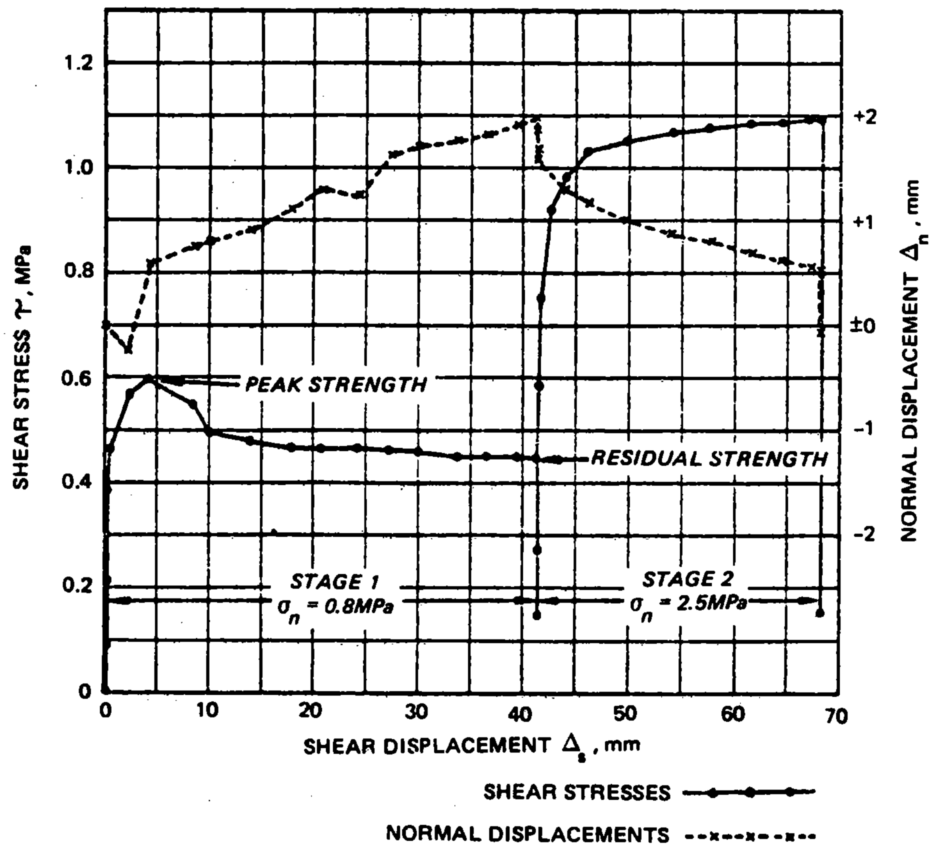



Fig. 5. Shear stress - displacement graphs.

NOTE 11—An independent check on the residual friction angle should be made by testing in the laboratory two prepared flat surfaces of the representative rock. The prepared surfaces should be saw-cut and then ground flat with No. 80 silicon carbile grit.

(f) Having established a residual strength, the normal stress may be increased or reduced (Note 12) and shearing continued to obtain additional residual strength values. The specimen should be reconsolidated under each new normal stress (see paragraph 3.2(d)) and shearing continued according to criteria given in 3.3(c) to 3.3(e).

NOTE 12--The normal load should when possible be applied in increasing rather than decreasing stages. Reversals of shear direction or resetting of the specimen block between normal load stages, sometimes used to allow a greater total shear displacement than would otherwise be possible, are not recommended because the shear surface is likely to be disturbed and subsequent results may be misleading. It is generally advisable, although more expensive, to use a different specimen block

(g) After the test, the block should be inverted, photographed in color, and fully described (see paragraph 5.1). Measurements of the area, roughness, dip, and dip direction of the sheared surface are required, and samples of rock, infilling, and shear debris should be taken for index testing.

## 4. Calculations

4.1 A consolidation curve (Fig. 4) is plotted during the consolidation stage of testing. The time $t_{100}$ for completion of "primary consolidation" is determined by constructing tangents to the curve as shown. The time to reach peak strength from the start of shear loading should be greater than 6 $t_{100}$ to allow pore pressure dissipation (see Note 10).

4.2 Displacement readings are averaged to obtain values of mean shear and normal displacements $\Delta_s$ and $\Delta_n$. Lateral displacements are recorded only to evaluate specimen behavior during the test, although if appreciable they should be taken into account when computing corrected contact area.

4.3 Shear and normal stresses are computed as follows:

$$\text{Shear stress} \quad \tau = \frac{Ps}{A} = \frac{Psa \cos\alpha}{A}$$

$$\text{Normal stress} \quad \sigma_n = \frac{Pn}{A} = \frac{Pna + Psa \sin\alpha}{A}$$

where Ps = total shear force; Pn = total normal force

Psa = applied shear force; Pna = applied normal force

$\alpha$ = inclination of the applied shear force to the shear plane (if $\alpha = 0$, $\cos\alpha = 1$ and $\sin\alpha = 0$).

A = area of shear surface overlap (corrected to account for shear displacement)

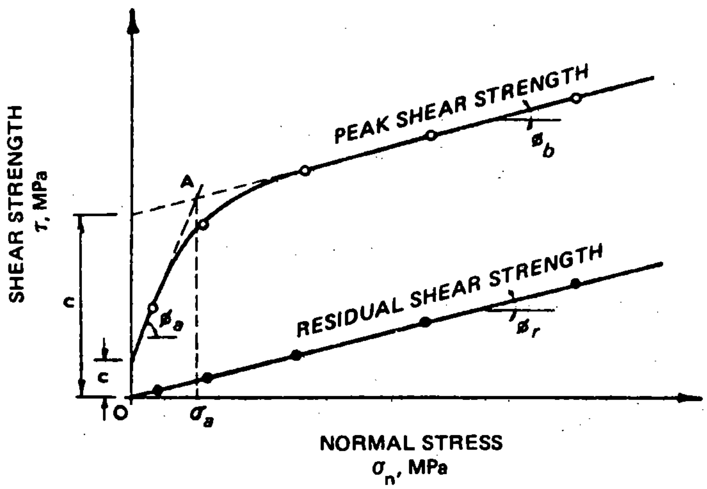
If $\alpha$ is greater than zero, the applied normal force should be reduced after each increase in shear force by an amount Psa sin $\alpha$ in order to maintain the normal stress approximately constant. The applied normal force may be further reduced during the test by an amount

$$\frac{\Delta_s \text{ (mm)} \cdot Pn}{700}$$

to compensate for area changes.

4.4 For each test specimen graphs of shear stress (or shear force) and normal displacement versus shear displacement are plotted (Fig. 5), annotated to show the nominal normal stress and any changes in normal stress during shearing. Values of peak and residual shear strengths and the normal stresses and shear and normal displacements at which these occur are abstracted from these graphs (Note 2).

4.5 Graphs of peak and residual shear strengths versus normal stress are plotted from the combined results for all test specimens. Shear strength parameters $\phi_a$, $\phi_b$, $\phi_r$, c', and c are abstracted from these graphs as shown in Fig. 6.




$\phi_r$ = residual friction angle

$\phi_a$ = apparent friction angle below stress $\sigma_a$; point A is a break in the peak shear strength curve resulting from the shearing off of major irregularities on the shear surface. Between points O and A, $\phi_a$ will vary somewhat; measure at stress level of interest. Note also that $\phi_a = \phi_u + i$, where $\phi_u$ is the friction angle obtained for smooth surfaces of rock on rock and angle i is the inclination of surface asperities.


Fig. 6. Shear strength - normal stress graph.

$\phi_b$ = apparent friction angle above stress level $\sigma_a$ (Point A); note that $\phi_a$ will usually be equal to or slightly greater than $\phi_r$ and will vary somewhat with stress level; measure at the stress level of interest$^r$.

c' = cohesion intercept of peak shear strength curve; it may be zero.

c = apparent cohesion at a stress level corresponding to $\phi_b$.

5. Reporting of Results

5.1 The report should include the following:

(a) A diagram, photograph, and detailed description of test equipment and a description of methods used for specimen preparation and testing. (Reference may be made to this "suggested method," stating only departures from the prescribed techniques).

(b) For each specimen, a full geological description of the intact rock, sheared surface, filling, and debris preferably accompanied by relevant index test data (e.g., roughness profiles and Atterberg limits, water content, and grain-size distribution of filling materials).

(c) Photographs of each sheared surface together with diagrams giving the location, dimensions, area, dip, and dip direction and showing the directions of shearing and any peculiarities of the blocks.

(d) For each test block, a set of data tables, a consolidation graph, and graphs of shear stress and normal displacement versus shear displacement (e.g. Figs. 3, 4, and 5). Abstracted values of peak and residual shear strengths should be tabulated with the corresponding values of normal stress and shear and normal displacement.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strengths versus normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).